Muon spin relaxation study of spin-glass freezing in the Heusler compound Ru$_{1.9}$Fe$_{0.1}$CrSi\textsuperscript{\dagger}

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The magnetic properties of the Heusler compounds Ru$_{2-x}$Fe$_x$CrSi have attracted interest. It has been revealed that Fe-rich compounds are ferromagnetic\textsuperscript{1}) and that the Ru-rich compound Ru$_2$CrSi shows an antiferromagnetic transition at $T_N = 14$ K.\textsuperscript{2)} Although the Ru-rich compound Ru$_{1.9}$Fe$_{0.1}$CrSi was found to show a peak in magnetic susceptibility at $T_N \sim 30$ K, which seemed to indicate an antiferromagnetic transition, no phase transition was found around $T_N$ or at any other temperatures in the specific heat.\textsuperscript{3,4)} Instead, the difference between the magnetic susceptibilities observed in a zero-field-cooling process and a field-cooling process increased significantly below $T_g \sim 15$ K, which was regarded as the onset of strong irreversibility.\textsuperscript{3)} This observation suggests the formation of a spin-glass (SG) state. In order to reveal the nature of the magnetic transitions, we have performed zero-field (ZF) and longitudinal-field (LF) muon-spin-relaxation ($\mu$SR) measurements for Ru$_{1.9}$Fe$_{0.1}$CrSi. The measurements were carried out at the RIKEN-RAL Muon Facility using a spin-polarized single-pulse positive surface muon beam. In these measurements, the time spectra of muon spin depolarization consisted of two components, and the asymmetry, $A_0(t)$, can be expressed as

\[ A_0(t) = A_1 \exp(-\lambda_1 t) + A_2 \exp(-\lambda_2 t). \]  

The first and second terms represent the fast and slow relaxation components, respectively, and $\lambda_1$ and $\lambda_2$ are the muon spin relaxation rates for each component. The initial asymmetry $A_0$ is $A_0(0) = A_1 + A_2$.

The parameters in Eq. (1) were obtained from the fitting of the time spectra, and these temperature dependences in the ZF-$\mu$SR measurement are shown in Fig. 1. As shown in the figure, a peak of the relaxation rates was observed at $\sim 16$ K, and this suggests the onset of spin freezing at $\sim T_g$. Furthermore, LF-$\mu$SR measurement for different values of magnetic field was performed at 0.3 K, which confirmed the presence of a static internal field. The internal field was estimated to be approximately 0.1308 ± 0.005 T. From these results we conclude that SG freezing occurs at $T_g$.

On the other hand, an anomaly in the relaxation rate of ZF-$\mu$SR, indicating a phase transition, appeared to be absent around $T_N$, whereas with decreasing temperature a large decrease in the initial asymmetry and a gradual increase in the relaxation rates were observed starting at $\sim 40$ K, which is slightly higher than $T_N$. The loss of the initial asymmetry may have been caused by a static internal field. To investigate the origin of the large decrease in the initial asymmetry below $\sim 40$ K, we performed LF-$\mu$SR measurements as a function of magnetic field $H_{LF}$ between $T_g$ and $\sim T_N$. The $H_{LF}$ dependence of $A_2$ was analyzed, and it was found that at temperatures below 30 K, $A_2$ increases from approximately the same field as at 0.3 K. This analysis suggests that a static field arises at the muon site from temperatures higher than $T_N \sim 30$ K and the value of the static field does not change much below $\sim 30$ K. These results indicate an inhomogeneous magnetic state. It appears that the formation of independent spin-frozen regions begins at $\sim 40$ K. As the temperature decreases, these static regions extend gradually, and this results in the observed decrease in the initial asymmetry. The correlation between static regions becomes larger and eventually SG freezing occurs at $T_g$.

References

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Fig. 1. Temperature dependences of (a) $A_0 = A_1 + A_2$ and $A_2$, and (b) $\lambda_1$ and $\lambda_2$, for ZF-$\mu$SR. Solid lines are guides to the eye.